Review of 62 risk analysis methodologies of industrial plants

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Review of sixty two risk analysis methodologies of industrial plants

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Abstract

Since a few ten or so years, many methodologies have been developed to lead a risk analysis on an industrial plant. In this paper, sixty two methodologies have been identified. Methodologies have been separated into three different phases (identification, evaluation and hierarchisation). In order to understand their functioning, it seemed interesting to look at input data, methods used, output data obtained and to rank them in several classes. All the input data have been grouped together into seven classes (plan or diagram, process and reaction, products, probability and frequency, policy, environment, text and historical). The methods have been ranked in six classes based on four usual criteria (qualitative, quantitative, deterministic, probabilistic). Finally, the output data have been classified in four classes (management, list, probabilistic, hierarchisation). This classification allowed to detail risk analysis methodology. In the aim to understand the functioning of these methodologies, the connections between the three criteria previously defined have been brought to the fore. Then the paper deals with the application fields and the main limitations of these methodologies. So, the hierarchisation phase is tackled and the type of scale used too. This paper highlights the difficulty to take into account all risks of an industrial plant and suggests that there is not only one general method to deal with the problematic of industrial risks.

Keywords : risk, analysis, methodology, industrial plant, hierarchisation.

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1- Introduction

The industrial risk problematic and the diversification of risk types have increased consequently with the industrial development. In the same time, the risk acceptability threshold of the population has decreased. In response to this preoccupation, competent authorities and industrialists have developed methodologies and tools for risk prevention and protection, as well as crisis management.

To face up to major accidents, a previous analyse should be done. The forward-looking risk analysis allows to do an exhaustive identification of potential hazardous sources to prevent accident scenarios and to assess potential impact on human, environmental and equipment targets in order to propose prevention or protection [1]. The risk analysis methodologies focus on the main hazard sources. Two principal sources of risk may be brought to the fore :

- industrial establishment;
- dangerous goods transportation

These two types of sources are quite different. At first sight, the quantities involved are really different, and the environment is not evolutionary for an industrial site at the opposite of the case of dangerous goods transportation.

So, to analyse and to manage safety aspects, various approaches had been proposed, they focus on organizational and technical sight. Sixty two risk analysis methodologies are set out in the following paper.

2- Risk analysis methodologies

The management of major industrial risk should be one of the most important preoccupation for operators. To deal with this problem many risk analysis methodologies were developed by industrialists and competent authorities.

2.1- Description of methodologies

This work allowed to find more than sixty risk analysis methodologies which may include three main phases :

- an identification phase based on a site description (hazardous activities, products and equipments). Those data are necessary to develop the processes of the methodologies,

- an evaluation phase to realize a quantification of risk. There are two ways to lead this part, a deterministic approach and / or a probabilistic approach. This evaluation gives the consequences of scenarios which were previously found and allows to take into account their impacts on the industrial site or on its vicinity.

- a hierarchisation phase which aims at ranking some results obtained in the two previous phases in order to put preponderant risks forward. Thanks to this hierarchisation, the most important risks should be solved at first.

The phase of risk identification is essential, because it puts the bases of the risk analysis. Indeed, the data of risk identification will be the input of the evaluation and / or hierarchisation phases. Therefore it is necessary to make an identification phase in an exhaustive way, to obtain the best results.

The phase of risk evaluation should be realized according two different approaches :

- either by the evaluation of damages consequences (deterministic approach),

- or by the evaluation of accident probability (probabilistic approach).

The phase of risk hierarchisation ranks the risks obtained in the previous phase, in order to implement modifications or corrective actions on the most severe risk systems.

A risk analysis methodology does not necessary contain these three phases. It can be constituted of only the following combinations :

- an identification phase,
- an identification and evaluation phases,
- or an identification, evaluation and hierarchisation phases.

However methodologies may be, to carry out a risk analysis three kinds of elements are required :

- the output data expected,
- the input data available,
- the selected method,

Indeed, users propose some objectives to reach (output data expected), next users collect information concerning the studied system (input data available), at last users chose the method applied according to the two previous elements.

2.1.1- Types of method

The used methods can be described according to four properties :

- Deterministic
- Probabilistic
- Qualitative
- Quantitative

These methodologies may be classified in two principal groups, one qualitative and the other quantitative. Each group may be divided into three categories :

- only deterministic,
- only probabilistic,
- a combination of deterministic and probabilistic approach.

The deterministic methods are based on the products, equipments and on the consequence quantification for various targets like people, environment and equipments. The probabilistic methods are based on the probability or frequency of hazardous situation apparition or the occurrence of potential accident. The probabilistic methods are mainly focused on failure probability of equipment or their component. On the other hand, deterministic and combined deterministic and probabilistic methods are used to analyse the whole industrial establishment.

The classification of the methods are based on type of output data. In each category, methods can be ranked from the more simple which are constituted of one step only to the more complex which are based on the three steps. The complex methods are generally composed of modules issued from simple methods and other modules are added in order to realize a risk analysis more complete with results easier to analyse.

In the table n°1, sixty two methodologies are ranked according to the four criteria previously defined.

The great majority of methods are determinist, historically operators and public organisations had initially try to quantify damages and consequences of potential accidents, before to understand why and how it was occurred.

2.1.2- Types of input data

The input data may be technical like process characteristics or qualitative like safety policy. The analysis of sixty two methods lead us to propose seven classes of input data. For each classes some information is given on the type of input data.

- **Plans or diagrams** are related to the description of the site, the installation, the units, the fluid networks, the safety barriers and the storages.
- **Process and reactions** are related to operations and tasks description, physical and chemical features of process, kinetic and calorimetrical parameters, operating conditions and normal functioning conditions.
- **Substances** are related to the type of substance, the physical and chemical properties, the quantities and the toxicological data.
- **Probability and frequency** are related to the type of failure, the probability and frequency of failure, the human failure, the failure rate and the exposure probability.
- **Policy and Management** are related to the maintenance, the organization, the safety policy, the Safety Management System, the transport management and equipment cost.
- **Environment :** is related to the site environment, the topographical data and the population density.
- **Text and historical knowledge** are related to the standard and regulations, and historical knowledge.

These input data are summarised in the table n°2. This table gives connections between input data and the methodologies reviewed.

Most methods are based on a general description of the site (Plans and Diagrams) and few methods take into account the Environment.

2.1.3- Types of output data

The output data may be qualitative like recommendations or quantitative like index of risk level for example. From the review of sixty two methods, four classes of output data can be proposed :

- **Management** is related to actions, recommendations, modifications, and formation or operation procedures.
- **Lists** are related to lists of errors, hazards, domino effects, causes/consequences, failures and damages, critical activities, failure mode, accident initiators, vulnerable place and major accident scenarios.
- **Probabilistic** is related to failure rate, reliability, scenarios or damages probability, accident frequency.
- **Hierarchisation** is related to level risk index, severity and criticity, fire, explosion, toxic leakage index, organizational index, classification according to type of risk.

The connections between output data and methodologies are presented in the table n°3.

Output data like Management and Lists are based on expert choice and give qualitative results while output data like Probabilistic and Hierarchisation give quantitative results.

2.1.4- Links between input data, output data and methods

Now, it seems to be relevant to underline how links between input data, method and output data are functioning. The table n°4 can be used according to whether the user expects some results or has some available data :

- First, if industrialists need a certain type of results, then they read table n°4 by results (output data) columns. So different types of methods are proposed and finally necessary input data are identified.
- Second, if only several input data are available, then the user reads the table n°4 by input data columns. The combining of available input data allows to show which methods are conceivable to lead risk analysis.

The table n°4 is a synthesis of the study and a tool for an identification of which methods could be used according objectives and available input data.

The analysis of precedent table n°4 brings to the fore that many input data are necessary to realize qualitative & deterministic risk analysis and for quantitative and deterministic or deterministic & probabilistic risk analysis.

However qualitative or quantitative methods are, results are the most complete when both deterministic & probabilistic methods are used.

Probabilistic methods need a few input data, but they don't take into account some specificities of the industrial establishment like Policy or Environment for example.

Now, the functioning of methodologies have been brought to the fore, and it still has to tackle two important points :

- on the one hand, the application fields of those methodologies,
- and on the other hand, their main limitations.

2.2- Application fields of methodologies

The application field of these different methodologies can be ranked into three categories (table n°5). The first, which is the most important in number of developed methodologies, concerns industrial site. Generally, some methodologies are developed for specific application or process and they aren't transposable on different type of industrial establishment.

The second application field is the transportation of dangerous goods.

The third one allows to take into account human factor in a specific environment.

Some methodologies can be used for various purposes and several application fields (to illustrate, the most general methods are "What if" and "Safety Analysis").

2.3- Limitations of methodologies

The main limitations of those methodologies may be summarised in the following points :

- The more general the methodology is, the less it takes into account the specificities of the studied case.
- On the contrary, if the methodology is too specific it is less transposable to another case.
- Knowledge of the people who are participating in the risk analysis are quite important (different type of competences and people involvement).
- For probabilistic analysis, the validity of data is a decisive parameter.
- The taking into account of the updating of data consume a lot of timework.
- For some methodologies, the operational application is difficult to realize because of the lack of description. It seems to be useful to provide a guide book to explain how methodologies may be used.

- The complexity of methods requires specific training for their implementation.
- It can be noticed that there is a great disconnection between risk analysis methodologies and human factor.

A new trend shows a need to have results more quickly exploitable. So, the output data of evaluation phase must be completed by an additional step : the hierarchisation phase.

3- The risk hierarchisation

The recent evolution in risk analysis methodologies shows that easily applicable methods are proposed with a risk level index as result. The hierarchisation constitutes the action to organize some elements, data, or events in increasing or decreasing order with the help of classification tabs in the aim to bring out the main points for analysis. These methodologies are simple and rapid to use, data tables are usually available for the hierarchisation phase.
The association between risk level and geographical zones on site is primordial to have a good safety management.
These different methodologies including hierarchisation step are gathered in the table n°6.

Methodologies with hierarchisation phase are almost all quantitative and deterministic. They are based on the development of a risk level index calculated for each element, unit or studied area in order to rank them. This ranking provides the way to identify clearly critical areas on industrial site. Thus it allows to realize priority actions in order to reduce the probability of occurrence (prevention) or to reduce the consequences of an accident (protection including emergency response).

To calculate this index, several parameters characterizing the site and processes are identified. Then these parameters are ranked with the help of scales which are provided in a guide and which can be based on a deterministic or probabilistic approach.

The deterministic scales can be quantitative or qualitative for the following variables which are :

- **Internal hazard of substances and equipments :**
  - reaction types (hydrolysis, oxidation, reduction, polymerisation,...)
  - reaction parameters (stability, reactivity, exothermically, pressure or temperature of reaction,...)
  - physical and chemical properties of substances, their toxicity with a correlation dose/effect and the study of their incompatibility.
  - quantities of substances used and stored
  - storage characteristics (pressure, temperature,...).

- **severity of the consequences :**
  - human damage types (over pressure blast, thermal flux, toxicity).
  - equipment damage types.
  - environmental damage types.
  - financial loss on equipment or production.

- **Layout and environment :**
  - distances between dangerous units of an industrial site.
  - population density inside and outside the industrial site.

The probabilistic scales are quantitative and they are made of variables which are :

- occurrence frequency of hazardous event
- incident or accident frequencies taking into account historical knowledge.
- consequences probabilities (fatalities, structure damages, ground or water pollution, ...).

The various scales have been developed for several types of application according to the particularities of certain industrial site in order to rank the risk in consistent manner. To generalize hierarchisation scale, it seems to be necessary to elaborate an exhaustive list of influencing risk factors from many industrial sites and to take into account human, environmental and equipment damages.

In fact, the hierachisation phase allow a data processing more advanced in order to rank risks on the studied area (risk level index). This ranking provides a help decision for decision-makers (industrialists and competent authorities).

4- Conclusion

The used of risk analysis methodologies contribute to prevent accidents and to be prepared for emergency response. This work based on the review of sixty two methodologies shows the difficulty to take into account all risks of an industrial site.. This paper highlights the different types of input data, methods, output data and their links. A risk analysis methodology can be simple and focusing only on identification of hazards or a combined risk analysis methodology. A combined risk analysis methodology may be composed of several simple risk analysis methodologies, with an identification, estimation and hierarchisation phases in order to obtain a risk level index for example. The recent development of risk analysis methodologies strives towards easily applicable methods with a hierarchisation phase which is based on specific scales depending on the studied installation. The application fields of methodologies are industrial site, hazardous goods transportation and human factors. The human factor risk analysis is often disconnected with classical risk analysis, that is due to the complexity of human risk analysis. The type of results are recommendations, lists, risk level index, event frequency and damage probability.

The sixty two methodologies identified show that there is not an uniqueness of methods to realise a risk analysis. On the contrary, there is a need to combine several methodologies. The application of these methodologies requires experience to obtain good results. In fact, these sixty two methodologies can constitute a starting point of a thought to elaborate a new methodology. To elaborate a methodology it seems interesting to propose an initial draft of methods. Then its application on real industrial sites will allow to improve it so therefore its transferability to other cases will be easier.

The whole remarks introduce in this study, carry to propose a draft of an ideal risk analysis methodology.

First, the studied area must be cut in four parts to lead the risk analysis :

- the term source (industrial establishment)
- the flux (vector of propagation of accidents)
- targets (human, environmental and equipments)
- Control and management

These four identified parts must be described in an exhaustive way and their interaction too.

Second, the mainspring of risk analysis should allow an deterministic and probabilistic approach with a hierarchisation phase.

And Finally, the output data will be of two different types :

- qualitative in order to provide recommendations
- quantitative in order to evaluate the main consequences

This methodology present a overall processes of risk analysis in order to provide some way of improvement and a decision help.

References :

[1] P. Lagadec, « Politique, risque et processus de développement : Le risque technologique majeur », Thèse de doctorat d'état en science politique, Université des Sciences Sociales de Grenoble II, 1980.

[2] BGN, « Draft methodology on risk assessment of unit operations and equipment », Rase Project,1-50.

[3] B. Rasmussen, C. Whetton, « Hazard identification on plant functional modelling », Reliability Engineering and System Safety, 55, 77-84, 1997.

[4] E. Korjusiommi, R. Salo, R. Taylor, « Hazard analysis for batch processes and for special operations », In proceeding from 9th International Symposium Loss Prevention and Safety Promotion in the Process Industries, 422-431, 1998.

[5] F. I. Khan, S. A. Abbasi, « Techniques and methodologies for risk analysis in chemical process industries », Journal of Loss Prevention in the Process Industries, 11, 261-277, 1998.

[6] M. Nicolet-Monnier, « Integrated regional risk assessment : the situation in Switzerland », Int. J. Environment and Pollution, Vol 6, n°4-6, 441-461, 1996.

[7] A. Toola, « Plant level safety analysis », Journal of Loss Prevention in the Process Industries, vol 5, n°2, 119-124, 1992.

[8] H. M. Tweeddale, R. F. Cameron, S. S. Sylvester, « Some experiences in hazard identification and risk shortlisting », Journal of Loss Prevention in the Process Industries, vol 5, n°5, 279-288, 1992.

[9] R. Kennedy, B. Kirwan, « Development of a hazard and operability-based method for identifying safety management vulnerabilities in high risk systems », Safety Sciences, 30, 249-274, 1998.

[10] F. I. Khan, S. A. Abbasi, « OptHazop- an effective and optimum approach for Hazop study », Journal of Loss Prevention in the Process Industries, vol 10, n°3, 191-204, 1997.

[11] P. D. Sankey, « An insurer's involvement in the risk reduction process », In proceeding from 9th International Symposium Loss Prevention and Safety Promotion in the Process Industries, 441-450, 1998.

[12] P. W. H. Chung, E. Broomfield, S. H. Yang, « Safety related questions for computer-controlled plants : derivation, organisation and application », Journal of Loss Prevention in the Process Industries, 11, 397-406, 1998.

[13] S. Yang, P. W. H. Chung, « Hazard analysis and support tool for computer controlled processes », Journal of Loss Prevention in the Process Industries, 11, 333-345, 1998.

[14] C. Delvosalle, C. Fievez, F. Benjelloun, « Development of a methodology for the identification of potential domino effects in « Seveso » industries », In proceeding from 9th International Symposium Loss Prevention and Safety Promotion in the Process Industries, 1252-1261, 1998.

[15] N. W. Hurst, S. Young, I. Donald, H. Gibson, A. Muyselaar, « Measures of safety management performance and attitudes to safety at major hazard sites », Journal of Loss Prevention in the Process Industries, vol 9, n°2, 161-172, 1996.

[16] R. M. Pitblado, J ; C. Williams, D. H. Slater, « Quantitative assessment of process safety programs », Plant/Operations Progress, vol 9, n°3, 169-175, 1990.

[17] F. I. Khan, S. A. Abbasi, « Multivariate hazard identification and ranking system », Process Safety Progress, vol 17, n°3, 157-170, 1998.

[18] F. I. Khan, S. A. Abbasi, « Accident hazard index : a multi-attribute method for process industry hazard rating », Trans IChemE, vol 75, Part B, 217-224, 1997.

[19] P. Jäger, K. Kühnreich, « Approach to a systematic determination and evaluation of risk potential », In proceeding from 9th International Symposium Loss Prevention and Safety Promotion in the Process Industries, 393-403, 1998.

[20] American Institute of Chemical Engineers, « Dow's chemical exposure index guide », first edition, AIChE technical manual, NY, 1994.

[21] American Institute of Chemical Engineers, « Dow's fire and explosion index guide », 6eme edition AIChE technical manual, NY, 1987.

[22] C. S. Kao, Y. S. Duh, « Chemical runaway reaction hazard index and risk assessment », In proceeding from 9th International Symposium Loss Prevention and Safety Promotion in the Process Industries, 965-975, 1998.

[23] O. Dolladille, « Proposition d'une méthode d'analyse d'effet domino », Préventique-sécurité, n°44, 62-70, 1999.

[24] « La directive Seveso II : Annexe 6 », edition legislative, bul 230, 6933-6947, 1997.

[25] M. D. Troutt., H. H. Elsaid, « The potential value of SAATY's eigenvector scaling method for short-term forecasting of currency exchanges rates », Siam Review, Vol 38, 650-654, 1996.

[26] K. Oien, S. Sklet, L. Nielsen, « Development of risk level indicators for petroleum production platform », In proceeding from 9th International Symposium Loss Prevention and Safety Promotion in the Process Industries, 382-393, 1998.

[27] J. Holmberg, « Risk follow up by probabilistic safety assessment-experience from a finish pilot study », Reliability Engineering and System Safety, 53, 3-15, 1996.

[28] W. Jezler, « Earthquake safety of structures and installations in chemical industry in the context of risk analysis », In proceeding from 9th International Symposium Loss Prevention and Safety Promotion in the Process Industries, 414-421, 1998.

[29] A. Kusiak, A. Zakarian, « Risk assessment of process models », Computers Ind Engng, vol 30, 599-610, 1996.

[30] N. Larson, A. Kusiak, « Managing design processes : a risk assessment approach », IEEE Transactions on systems, man, and cybernetics- part A: systems and humans, vol 26, n°6, 749-759, 1996.

[31] K. J. M. Ham, H. J. C. M. van Kessel, T. Wiersma, « Experiences with a safety report according to Seveso II : a pilot project in the Netherlands », In proceeding from 9th International Symposium Loss Prevention and Safety Promotion in the Process Industries, 1326-1340, 1998.

[32] F. I. Khan, S. A. Abbasi, « Inherently safer design based on rapid risk analysis », Journal of Loss Prevention in the Process Industries, vol 11, 361-372, 1998.

[33] G. Tiemessen, J. P. van Zweeden, « risk assessment of the transport of hazardous materials », In proceeding from 9th International Symposium Loss Prevention and Safety Promotion in the Process Industries, 299-307, 1998.

[34] I. Puertas, J. C. Sanz C. Vaquero, M. Marono, R. Sola, « Procedure for the review of quantitative risk assessment of the process industries », In proceeding from 9th International Symposium Loss Prevention and Safety Promotion in the Process Industries, 283-288, 1998.

[35] I. A. Papazoglou, Z. Noivolianitou, O. Aneziris, M. Christou, « Probabilistic safety analysis in chemical installation », Journal of Loss Prevention in the Process Industries, vol 5, n°3, 181-191, 1992.

[36] C. Alonso, J. Gavalda, « a method to determine environmental risk in chemical process industries », In proceeding from 9th International Symposium Loss Prevention and Safety Promotion in the Process Industries, 1219-1227, 1998.

[37] D. G. Leeming, F.F. Saccomanno, « Use of quantified risk assessment in evaluating the risks of transporting chlorine by road and rail », Transportation Research Record, n°1430, 27-35, 1994.

[38] S. A. Gadd, D. G. Leeming, T. N. K. Riley, « Transport Riskat : the HSE quantified risk assessment tool for toxic and flammable dangerous goods transport by road and rail in Great Britain », In proceeding from 9th International Symposium Loss Prevention and Safety Promotion in the Process Industries, 308-317, 1998.

[39] Perhillon, « Risques Industriels Part 1 & 2 », CEA INSTN, 1992.

[40] W. P. G. Schlechter, « Facility risk review as a mean to addressing existing risk during the life cycle of a process unit, operation or facility », Int J Pres Ves & Piping, vol 66, 387-402, 1996.

[41] K. Davoudian, J. S. Wu, G. Apostolakis, « The work process analysis model (WPAM) », Reliability Engineering and System Safety, vol 45, 107-125, 1994.

	Risk Analysis Methodologies			
	n°*	Qualitative		Quantitative
deterministic	1	Action Errors Analysis AEA [2]	31	Accident Hazard Analysis AHI [17] [18]
	2	Checklist [5]	32	Annex 6 of SEVESO II Directive [24]
	3	Concept Hazard Analysis CHA [2] [3]	33	Chemical Runaway Reaction Hazard Index RRHI [22]
	4	Concept Safety Review CSR [2]	34	Dow's Chemical Exposure Index CEI [20]
	5	Failure Mode Effect Analysis FMEA [2] [5] [6]	35	Dow's Fire and Explosion Index FEI [17] [21]
	6	Goal Orinted Failure Analysis GOFA [2]	36	Fire and Explosion Damage Index FEDI [17]
	7	Hazard and Operability HAZOP [2] [5] [6] [8] [9]	37	Hazard Identification and Ranking HIRA [5] [18]
	8	Human Hazard and Operability HumanHAZOP [9]	38	Instantaneous fractionnal loss index IFAL [5] [17]
	9	Insurers involvement in risk reduction process [11]	39	Methodology of domino effects analysis [23]
	10	Manager [16]	40	Methods of potential risk determination and evaluation [19]
	11	Optimal Hazard and Operability OptHAZOP [5] [10]	41	Mond Fire Explosion and Toxicity Index FETI [5] [17]
	12	Plant Level Safety Analysis PLSA [7]	42	SAATY methodology [25]
	13	Potential domino effects identification [14]	43	Toxic Damage Index TDI [17]
	14	Preliminary Risks Analysis PRA [2] [6]		
	15	Process Risk Management Audit PRIMA [15]		
	16	Profile Deviation Analysis PDA [4]		
	17	Safety related questions for computer controlled plants [12] [13]		
	18	Seqhaz Hazard Mapping SHM [4]		
	19	Sneak Analysis [2]		
	20	Task Analysis TA [2]		
	21	What if? Analysis [2] [5] [6]		
	22	World Health Organisation WHO [5]		
probabilistic	23	Accident Sequences Precursor ASP [27]	44	Defi method [2]
	24	Delphi Technique [2]	45	Event Tree Analysis ETA [2] [6] [33] [38]
	25	Earthquake safety of structures and installations in chemical industries [28]	46	Fault Tree Analysis FTA [2] [5] [6]
			47	Maintenance Analysis MA [2]
			48	Short Cut Risk Assessment SCRA [2]
			49	Work Process Analysis Model WPAM [41]
deterministic & probabilistic	26	Maximum Credible Accident Analysis MCAA [5]	50	AVRIM2 [31]
	27	Reliability Block Diagram RBD [2]	51	Facility Risk Review [40]
	28	Safety Analysis SA [5]	52	Failure Mode Effect Criticality Analysis FMECA [2]
	29	Safety Culture Hazard and Operability SCHAZOP [9]	53	IDEF3 [29] [30]
	30	Structural Reliability Analysis SRA [2]	54	International Study Group on Risk Analysis ISGRA [5]
			55	IPO Risico Berekening Methodiek IPORBM [33]
			56	Method Organised Systematic Analysis of Risk MOSAR [2] [39]
			57	Optimal Risk Assessment ORA [5]
			58	Probabilistic Safety Analysis PSA [5] [35]
			59	Quantitative Risk Assessment QRA [2] [5] [26] [34] [35] [36] [37]
			60	Rapid Ranking RR [8] [30]
			61	Rapid Risk Analysis Based Design RRABD [32]
			62	Risk Level Indicators RLI [26]

Table n°1 : Classification of risk analysis methodologies

* each methodologies is refering by a number.

TYPES	INPUT DATA	METHODOLOGIES*
Plan & diagram		
	site installations units fluid or gas networks functionning safety barriers storages	2,3,4,5,7,8,11,13,14,15, 18,19,21,22,23,26,27,30, 31,34,35,36,37,38,39,40, 41,42,43,45,46,47,50,51, 52,53,56,57,59,61,62
Process & reactions		
	operations description tasks description reactions and physical and chemical features process characteristics kinetics and calorimetrical parameters normal functionning conditions operating conditions	2,3,7,8,10,11,12,14,16, 19,20,21,33,35,36,37,40, 41,42,43,54
Products		
	products types, physical and chemical properties quantities toxicological data	11,12,13,14,16,26,31,32, 33,34,35,36,38,40,41,42, 43,51,54,55,56,58
Probability & frequency		
	failure type failure probability initiation and failure frequencies human failure failure rate exposure probability	1,12,23,24,25,26,27,28, 29,30,44,46,47,48,49,50, 51,52,53,58,59,60
Policy & Management		
	maintenance organization safety policy SMS transport management equipments cost	2,9,10,15,17,29,36,42, 49,51,55
Environment		
	site environment topographical data population density	11,19,31,34,36,37,42,51
Texts & historical knowledge		
	standards regulations and documents historical knowledge	4,5,13,14,18,31,35,39, 41,42,51,52,59,61

Table n°2 : Connections between input data and methodologies.
* the number refers to the methodologies presented in table n°1

TYPES	OUTPUT DATA	METHODOLOGIES*
Management		
	actions recommendations modifications formation and operation procedures	3,4,5,6,7,9,10,11,15,16,20, 39,50,51,59,60
List		
	list of errors estimation/list of risks list of domino effects list cause/consequence failure, damage list of installation critical activities list of failure mode list accident initiators list of vulnerable place list of major scenarios	1,2,5,6,7,8,11,12,13,14,17, 19,21,22,23,24,26,28,29, 30,39,46,47,48,49,50,51, 53,54,56,57,59,60,61
Probabilistic		
	failure rate reliability scenarios or damages probability accident frequency	23,24,25,26,27,28,29,30, 44,45,49,53,54
Hierarchisation		
	risk index/level severity/criticity fire/explosion index toxic leakage index organizational risk index type risk classification	11,18,25,31,32,33,34,35, 36,37,38,40,41,42,43,51, 52,55,56,58,61,62

Table n°3 : Links between output data and methodologies.
* the number refers to the methodologies presented in table n°1

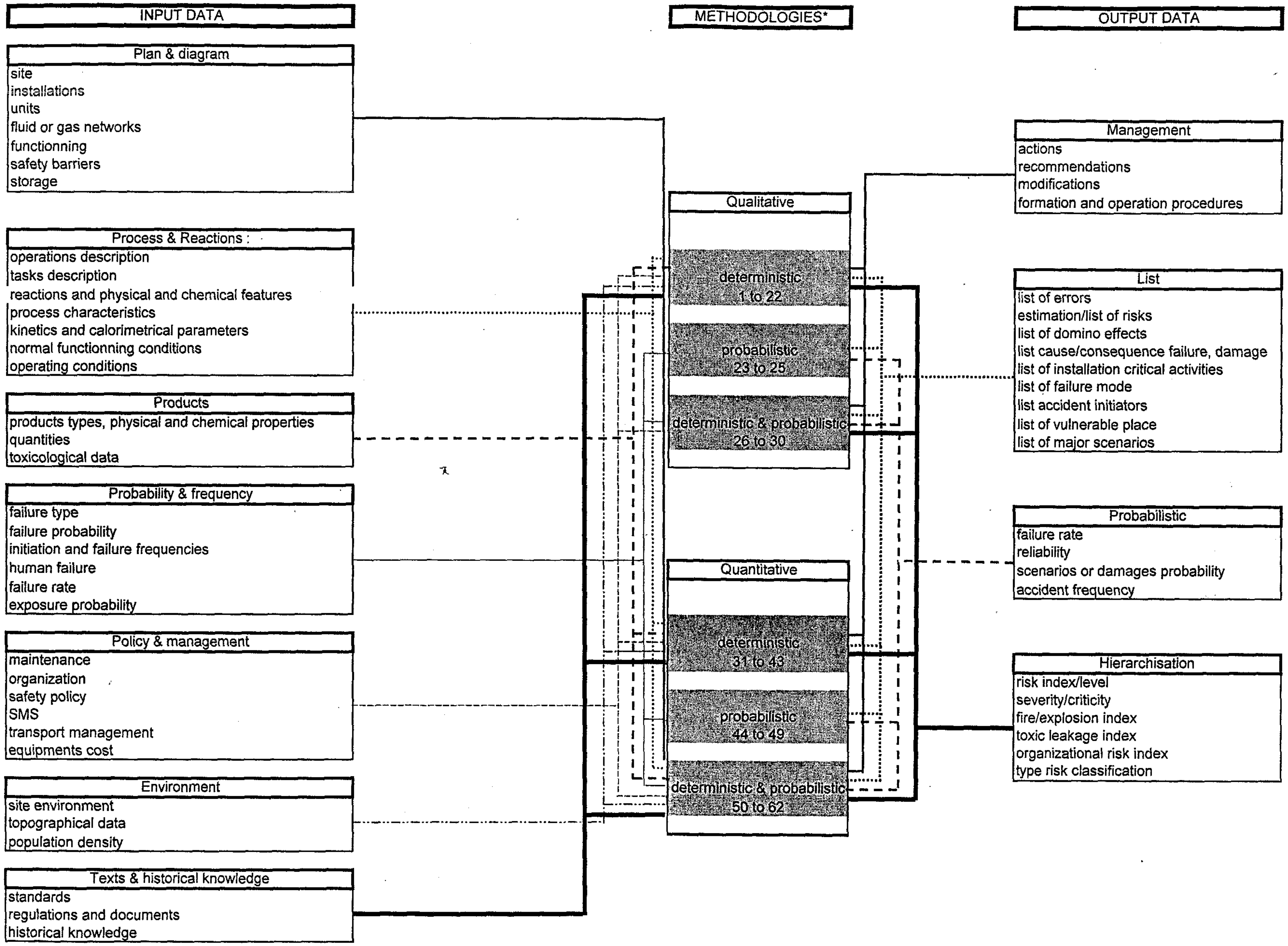

Table n°4 : Links between input data, methods and output data.
* the number refers to the methodologies presented in table n°1

	Methodologies	
industrial site	Accident Hazard Analysis AHI [17] [18]	Method Organised Systematic Analysis of Risk MOSAR [2] [39]
	Accident Sequences Precursor ASP [27]	Methodology of domino effects analysis [23]
	Annex 6 of SEVESO II Directive [24]	Methods of potential risk determination and evaluation [19]
	AVRIM2 [31]	Mond Fire Explosion and Toxicity Index FETI [5] [17]
	Checklist [5]	Optimal Hazard and Operability OptHAZOP [5] [10]
	Chemical Runaway Reaction Hazard Index RRHI [22]	Optimal Risk Assessment ORA [5]
	Concept Hazard Analysis CHA [2] [3]	Plant Level Safety Analysis PLSA [7]
	Concept Safety Review CSR [2]	Potential domino effects identification [14]
	Defi method [2]	Preliminary Risks Analysis PRA [2] [6]
	Delphi Technique [2]	Probabilistic Safety Analysis PSA [5] [35]
	Dow's Chemical Exposure Index CEI [20]	Profile Deviation Analysis PDA [4]
	Dow's Fire and Explosion Index FEI [17] [21]	Quantitative Risk Assessment QRA [2] [5] [26] [34] [35] [36] [37]
	Earthquake safety of structures and installations in chemical industries [28]	Rapid Ranking RR [8] [30]
	Event Tree Analysis ETA [2] [6] [33] [38]	Rapid Risk Analysis Based Design RRABD [32]
	Facility Risk Review [40]	Reliability Block Diagram RBD [2]
	Failure Mode Effect Analysis FMEA [2] [5] [6]	Risk Level Indicators RLI [26]
	Failure Mode Effect Criticality Analysis FMECA [2]	SAATY methodology [25]
	Fault Tree Analysis FTA [2] [5] [6]	Safety Analysis SA [5]
	Fire and Explsion Damage Index FEDI [17]	Safety Culture Hazard and Operability SCHAZOP [9]
	Goal Orinted Failure Analysis GOFA [2]	Safety related questions for computer controlled plants [12] [13]
	Hazard and Operability HAZOP [2] [5] [6] [8] [9]	Seqhaz Hazard Mapping SHM [4]
	Hazard Identification and Ranking HIRA [5] [18]	Short Cut Risk Assessment SCRA [2]
	IDEF3 [29] [30]	Sneak Analysis [2]
	Instantaneous fractionnal loss index IFAL [5] [17]	Structural Reliability Analysis SRA [2]
	Insurers involvement in risk reduction process [11]	Toxic Damage Index TDI [17]
	International Study Group on Risk Analysis ISGRA [5]	What if? Analysis [2] [5] [6]
	Maintenance Analysis MA [2]	World Health Organisation WHO [5]
	Maximum Credible Accident Analysis MCAA [5]	
transport	Checklist [5]	Hazard and Operability HAZOP [2] [5] [6] [8] [9]
	Event Tree Analysis ETA [2] [6] [33] [38]	IPO Risico Berekening Methodiek IPORBM [33]
	Failure Mode Effect Analysis FMEA [2] [5] [6]	Quantitative Risk Assessment QRA [2] [5] [26] [34] [35] [36] [37]
	Fault Tree Analysis FTA [2] [5] [6]	What if? Analysis [2] [5] [6]
human	Action Errors Analysis AEA [2]	Safety Culture Hazard and Operability SCHAZOP [9]
	Human Hazard and Operability HumanHAZOP [9]	Task Analysis TA [2]
	Manager [16]	Work Process Analysis Model WPAM [41]
	Process Risk Management Audit PRIMA [15]	

Table n° 5 : Application fields of risks analysis methodologies.

Methodologies with hierarchisation phase
Accident Hazard Analysis AHI [17] [18]
Annex 6 of SEVESO II Directive [24]
Chemical Runaway Reaction Hazard Index RRHI [22]
Dow's Chemical Exposure Index CEI [20]
Dow's Fire and Explosion Index FEI [17] [21]
Earthquake safety of structures and installations in chemical industries [28]
Facility Risk Review [40]
Failure Mode Effect Criticality Analysis FMECA [2]
Fire and Explsion Damage Index FEDI [17]
Hazard Identification and Ranking HIRA [5] [18]
Instantaneous fractionnal loss index IFAL [5] [17]
Methodology of domino effects analysis [23]
Methods of potential risk determination and evaluation [19]
Mond Fire Explosion and Toxicity Index FETI [5] [17]
Potential domino effects identification [14]
Probabilistic Safety Analysis PSA [5] [35]
Risk Level Indicators RLI [26]
SAATY methodology [25]
Seqhaz Hazard Mapping SHM [4]
Toxic Damage Index TDI [17]

Table n° 6 :Risks analysis methodologies with hierarchisation step